Novel STI Step-height Uniformity Control by Wet Etch Process in 4xnm CMOS Device

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Introduction
- HARP & HDP materials characteristic comparison
- The importance of step height uniformity control
- STI HARP wet etching uniformity performance by liquid HF

Step Height Uniformity Improvement
- Annealing effect
- Liquid HF (LHF) & gas HF (GHF) etching mechanism
- Process optimization result

Conclusion
Powerchip  STI Materials Comparison (HDP & HARP)

- High aspect ratio process (HARP) has been applied in shallow trench isolation (STI) for 45nm CMOS and beyond due to better gap fill ability.

**STI (Shallow Trench Isolation) Material Road Map**

<table>
<thead>
<tr>
<th>Generation</th>
<th>130 nm</th>
<th>65 nm</th>
<th>55 nm</th>
<th>4x nm</th>
<th>2x nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDP</td>
<td>A/R&lt;4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HARP</td>
<td>A/R~6</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**HDP (High density plasma):**
- Precursor: SiH$_4$ (silane)
- ✓ SiO$_2$ cross-linking before annealing
- ✓ Poor gap fill ability (A/R<4)

**HARP (High aspect ratio process):**
- Precursor: O$_3$ + TEOS (Si(OC$_2$H$_5$)$_4$)
- ✓ SiO$_2$ cross-linking after annealing
- ✓ Better gap fill ability (A/R~6)

Reaction equation:
SiH$_4$ + 2O$_2$ + Ar $\rightarrow$ SiO$_2$ + 2H$_2$O + Ar + ...

Deposition + Sputtering = HDP-CVD

HARP anneal Re-flow

Generation 130 nm 65 nm 55 nm 4x nm 2x nm
HDP A/R<4
HARP A/R~6

Seam-Free

SiO$_2$
HARP wet etching rate (E/R) is harder to be controlled than HDP in different STI width by conventional liquid HF (LHF).

- **HDP**: Good step height uniformity
- **HARP**: Worse step height uniformity
Step height control is necessary to avoid poly residue issue and Y% loss.

**Case 1:**
- Poly
- STI
- AA
- Step height
- Shallow Divot

**Case 2:**
- Poly
- STI
- AA
- Step height
- Deep Divot

Before poly gate etch

After poly gate etch

Poly residue free

Poly residue → Y% killer
Worse Step height Uniformity by LHF

- Step height (S/H) uniformity in different STI width is worse under LHF etching during well implant and gate oxide formation process.
- S/H in narrow STI width is lower than wide one and the bias is 18.5nm.

![Graph showing step height uniformity](image-url)

- Step height (S/H) uniformity in different STI width is worse under LHF etching during well implant and gate oxide formation process.
- S/H in narrow STI width is lower than wide one and the bias is 18.5nm.
Anneal Effect on Wet Etch Uniformity

- Annealed HARP quality is different from narrow to wide STI width.
- Etch amount (E/A) uniformity is worse in annealed HARP than without annealed one.
Annealed HARP Quality in Different STI Width

- Narrow STI width area: weak cross-linking & high impurity.
- Wide STI width area: strong cross-linking & low impurity.

**Weak Cross-linking**
- High Impurity

**Strong Cross-linking**
- Low Impurity

**STI width**
- Narrow → Wide

**LHF** (hardness dominate)
- Fast → Slow

**GHF** (diffusion dominate)
- Slow → Fast
LHF & GHF Etching Mechanism

- LHF: HARP cross-linking (hardness) dominate.
- GHF: gas diffusion is limited by HARP impurity.

**STI width**

- **Narrow**
  - LHF (Si-O-Si De-bonding)
  - Weak cross-linking $\Rightarrow$ E/R fast

- **Wide**
  - GHF (gas diffusion reaction)
  - Strong cross-linking $\Rightarrow$ E/R slow

**Impurity**

- High impurity $\Rightarrow$ E/R slow
- Less impurity $\Rightarrow$ E/R fast
LHF and GHF E/R in different STI width is opposite.
After optimizing the process flow by combining LHF and GHF, S/H bias through all STI width can be reduced from 18.2nm to 4.5nm.

The approach is very helpful for process window enlargement in following gate etch step.
<table>
<thead>
<tr>
<th>STI width</th>
<th>Narrow</th>
<th>Middle</th>
<th>Wide</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHF only</td>
<td><img src="LHF_only_Narrow.png" alt="Image" /></td>
<td><img src="LHF_only_Middle.png" alt="Image" /></td>
<td><img src="LHF_only_Wide.png" alt="Image" /></td>
</tr>
<tr>
<td>Step height (nm)</td>
<td>0</td>
<td>11.4</td>
<td>18.5</td>
</tr>
<tr>
<td>Optimized process (LHF + GHF)</td>
<td><img src="Optimized_Narrow.png" alt="Image" /></td>
<td><img src="Optimized_Middle.png" alt="Image" /></td>
<td><img src="Optimized_Wide.png" alt="Image" /></td>
</tr>
<tr>
<td>Step height (nm)</td>
<td>12.4</td>
<td>14.1</td>
<td>14.9</td>
</tr>
</tbody>
</table>
The cross-linking and impurity content of annealed HARP is different between STI width, which is key impact factors of STI wet etching uniformity.

E/R of LHF is related to oxide film hardness, on the other hand, E/R of GHF is limited by HARP impurity. Therefore, different HARP quality between STI width leads opposite E/A trend in LHF and GHF.

Low S/H bias (<5nm) can be achieved by combining LHF and GHF, and poly gate etch process window can be enlarged by this fine-tuned STI profile.
Thank you for your attention